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EVAPORATION MEMORANDUM NO. 37

DUPLICATE ALSO

THE QUALITY-CONTROL OF EVAPORIMETER DATA

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SUMMARY

Empirical factors to adjust monthly Penman potential evaporation estimates (albedo 0.25) are derived from comparisons between Penman estimates and evaporimeter data. It is shown that the seasonal sense and size of these factors is in step with the average seasonal pattern of soil temperatures at 30cm.

A scheme for the quality control of British evaporimeter data is proposed, using the empirical factors as a temporary expedient pending the results of a thorough examination of their significance.

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1. Introduction

Two of the best known devices for measuring potential evaporation (p.e.) are the evaporation tank and the simple, irrigated lysimeter. The British networks of these types of evaporimeters are too sparse to permit reliable quality-control to be exercised by means of "nearest neighbour" comparisons alone. Estimates of potential evaporation, using a combined energy balance and mass transfer formula (Penman 1948), may be made for any meteorological station at which air temperature, humidity, duration of bright sunshine (or totals of global or net radiation) and wind speed are measured or they may be obtained for any desired location using a system such as that described by Wales-Smith (1975). Numerous comparisons between Penman and evaporimeter p.e. totals have shown generally good agreement if the devices are well sited and well managed and the meteorological data (used for the p.e. estimates) are of good quality. If the calculated estimates of p.e. are to be used to assess the quality of evaporimeter data it is essential to ensure that these two types of measures of p.e. are entirely comparable.

2. Comparisons of monthly totals of evaporimeter Penman p.e.

Monthly totals of lysimeter p.e. were available for most months in 1971 from 27 lysimeter stations fairly evenly distributed over England, Scotland and Wales. Monthly Penman p.e. totals (using albedo 0.25) were calculated or carefully interpolated for all stations. Fig.1. (a) shows, for each month, the numbers of lysimeters which gave totals above, equal to or below the Penman p.e. estimates. It is clear that there is a systematic discrepancy; the Penman estimates tending to be higher than the evaporimeter measurements in the spring and summer and lower than measured p.e. in the autumn and winter. Fig.1.b. shows the percentages of available lysimeter totals above and below Penman p.e. each month.

On the assumption that the seasonal discrepancy was real and that the 1971 comparison included some poor as well as good quality lysimeter data a 53 station-year comparisons of monthly lysimeter and (Penman) estimated p.e. was made for instruments at 6 scientific establishments. The quantity plotted in Fig.2. is

E_{LYS}/E_{PENMAN} (lysimeter p.e. divided by Penman p.e.). The curve has been drawm by eye and whilst its position in the colder months is highly speculative it is clearly defined from March to October and lies well above unity in the winter.

The comparison was also carried out for black (or unpainted) evaporation tanks buried in the ground at 6 scientific establishments. The results of this 34 station-year comparison (Fig.3.) are in close accord with that made using lysimeter data.

3. Apparent relationship between the average seasonal discrepancy between Penman and evaporimeter p.e. and the change of earth temperature at 30cm depth.

It seemed likely that the systematic seasonal discrepancy might be associated with the storage in the soil of heat energy which the Penman formula would allocate to evaporation in the spring and summer and for the release of this energy, to enhance the evaporation estimated from energy balance and mass transfer calculations in the autumn and winter. Monthly averages of earth temperature at 30 cm are available for the period 1931-60. (Meteorological Office 1968) and values for 4 well-separated stations are plotted in Fig.4. It can be seen that the earth warms up from February to July and cools from August to February. This is in exact agreement with the empirical curves in Figs 2 and 3. It is assumed that the periods of increase and decrease of average soil temperature are respectively, periods of net heat flux into and out of the earth.

4. Empirical factors to adjust monthly estimates of Penman p.e. to allow for assumed, soil heat flux effects on seasonal evaporation and, perhaps for other effects not so far identified.

The assumption was made that monthly Penman potential evaporation totals summed over a year give a realistic result and that the seasonal discrepancy with measured values simply represents a re-distribution of "evaporative power" between months. On this basis empirical factors obtained from Figs 2 and 3. were modified for some winter months to give:

	J	F	M	A	M	J	J	A	S	O	N	D
E_L/E_p	3.8	1.7	.95	.92	.88	.90	.95	1.00	1.25	1.70	3.8	7.5
E_T/E_p	3.8	1.7	.95	.86	.85	.90	.95	1.00	1.12	1.55	4.6	10.0

These factors have been obtained for inland stations mostly situated at low altitudes (above sea level). Near coasts and on high ground surface wind speeds are, on average, higher than on low ground inland. The aerodynamic component in a Penman p.e. estimate will generally be much larger in a windy location than elsewhere. In winter the value of the (Penman) energy balance team is usually very small and absurdly large estimates of "corrected p.e." for, say, December would result from using the factor 7.5 with a p.e. estimate already fairly large due to high wind speed. Ideally quality-control would be performed on complete (March-Feb) years of data so that only the evaporative power released by stored heat would be distributed between the months with a ground-to-air net heat flux. As a rough practical expedient when delay cannot be accepted it seems reasonable to suggest that "corrected" Penman p.e. for Nov-Jan should never be lower than the "uncorrected" value and never higher than the following arbitrary multiples of the monthly average p.e. as given by Smith (1967).

Nov	Dec	Jan	Feb
2.5	3.0	2.5	2.0

5. Spatial variation of Penman p.e.

Wales-Smith (1972) has shown that monthly totals of Penman p.e. are closely correlated between pairs of stations several tens of miles apart.

In Fig.5. monthly totals of "corrected" (Penman) p.e. for each of the 27 lysimeters in 1971 are plotted in the y-direction against averages of "corrected" p.e. from each lysimeter's set of 3 nearest neighbours in the x-direction. Before being averaged, each "nearest neighbour corrected p.e. value" was multiplied by the ratio of its own average annual (Penman) p.e. to that of the station plotted in the y-direction. It is seen that the line of best fit, inserted by eye is a very close approximation to the 1.1.line. Hence it is considered reasonable to estimate evaporimeter p.e.

(a) by evaluating and "correcting" Penman p.e. at the lysimeter station, (b) by obtaining an estimate of "corrected" Penman p.e. from 3 nearest neighbour stations or (c) only if the data are of good quality - by adjusting measured p.e. totals by proportion of average annual p.e. and meaning the results from a station's 3 nearest neighbours.

As the results of (a) and (b) are so close (see Fig.5.) the simpler method (a) is proposed.

A measure of the likely accuracy of (c) the "3 nearest neighbours" method in any given case may be obtained by comparing the greatest difference between any two (out of the 3) estimates with the average monthly p.e. for the station "under test".

6. Provisional proposals for the quality-control of British evaporimeter data.

Pending modification following a full examination of the reasons for the systematic seasonal discrepancies between evaporimeter and Penman p.e. the following outline proposals for quality-control are made.

A quality-control and data processing system for irrigated lysimeter data.

(1) Punch the data from the working sheet in the following format:

RRRRF IIIIb WWWWF

where units are tenths of mm

and RRRR = rainfall (thrown back)

IIII = irrigation applied

WWWW = percolated water (thrown back)

F = flag b = space

(2) Flag accumulations A

(3) Compare RRRR with quality-controlled RRRR and substitute the second version if necessary with flag Q. This step takes care of accumulations of rainfall.

(4) Share accumulations of WWWW(equally) between the days in the accumulation period.

(5) Enter IIII = 0 for days when no irrigation applied.

(6) Work LLLL = IIII + RRRR - WWWW daily. (Some or all values of RRR may be the quality-controlled versions). LLLL = lysimeter evaporation.

(7) If LLLL can not be obtained for any day, obtain LLLL over as many days as possible and use this value, flagged "C" (LLLLC) for missing values.

(8) Run the arithmetical smoothing program (Wales-Smith 1975b) to remove the results of uneven rates of percolation not related to evaporation.

(9) Calculate n-day and calendar month L (see n-day system below).

(10) Calculate n-day and calendar month $\overline{L'}$

(11) Calculate n-day and calendar month P_2 (modified Penman p.e.).

(12) Calculate n-day and calendar month Δs for L' trios*

(13) Calculate $100\,\Delta/\overline{P_2}$ (where $\overline{P_2}$ is the appropriate average for the n-day or calendar month period) also calculate $100P_2/\overline{P_2}$ and $100\,\overline{L'}/\overline{P_2}$.

Note: Days when the lysimeter is frozen and/or snow-covered are treated as accumulations.

* where Δ is the greatest difference between a month's set of 3 L' or T' values.

n-day system. n-day periods

28 day month	6,6,6,5,5,	M
29 day month	6,6,6,6,5	M
30 day month	6,6,6,6,6	M
31 day month	6,6,6,6,7	M

(14) Print a comparison table of the format:

STATION NAME

Number

Month Year

	L,	L',	$100\Delta/\overline{P_2}$	P_2
1				
2				
3				
4				
5				
M				

* See section on Tanks

(15) Print in map form (see Fig.12 Wales-Smith (1975b))

$100\ L/\overline{P_2}$, $100P_2/\overline{P}_2$ and $100\ \overline{L}'/\overline{P}_2$

using labels L, $\overline{L}'$ and P_2

Action

1. One or more n-day totals (of L) appear(s) high or low.

Check daily L values in the period(s), estimate new n-day value(s) and individual day values and discuss with the station authority. If the authority states that an error was made, use the amended figures if they seem reasonable. If agreement can be reached print amended values in brackets. If agreement can not be reached print original total with an asterisk. (Asterisk = discrepancy between L and estimates thereof ($\overline{L}'$ and/or P_2) noted but not resolved).

2. More than one n-day total (of L) appear high or more than one n-day total appear low.

Consult 2.2.4. and Appendix 2 of Wales-Smith (1975b) and check on site, lysimeter management and observational technique. If a serious shortcoming is revealed and can not be removed, publication of the record should cease until it attains acceptable quality, If the necessary changes are made, print agreed, revised values in brackets. If all points are checked thoroughly without revealing any apparent shortcoming the data should be marked with a double asterisk. (Double asterisk =discrepancy between L and estimates thereof ($\overline{L}'$ and/or P_2) investigated but not yet resolved).

A quality-control and data processing system for evaporation tank data.

(1) Punch the data from the working sheet in the following format:

RRRRF FFFFb SSSSb

where units are tenths of mm

and RRRR = rainfall (thrown back)

FFFF =water level measurement at 09 GMT (thrown back)

SSSS = water level after adjustment (if any)

F = flag b = space

(2) Flag accumulations of R "A"

(3) Compare RRRR with quality-controlled RRRR and substitute the second version if necessary with flag Q. This step takes care of accumulations of rainfall.

(4) Work FFFF - SSSS on each line. FFFF - SSSS = WWWW (where WWWW is water loss; negative in case of condensation). Where a measurement has been missed, work WWWW and share (equally) between the days in the accumulation period.

(5) Work TTTT = RRRR + WWWW for each day. (TTTT = tank evaporation).

(6) If TTTT can not be obtained for any day, obtain TTTT over as many days as possible and use this value, flagged "C" (TTTTC) for missing values.*

(7) Calculate n-day and calendar month T (see "n-day system" for lysimeters)

(8) Calculate n-day and calendar month $\overline{T}'$.

(9) Calculate n-day and calendar month P_2

(10) Calculate n-day and calendar month Δs for T' trios

(11) Calculate $100\Delta/\overline{P}_2$ (where $\overline{P}_2$ is the appropriate average for the n-day or calendar month period)

(12) Print a comparison table of the format:

STATION NAME

Number Tank colour
Tank type
Month Year

	T	$\overline{T}'$	$100\Delta/\overline{P}_2$	P_2
1				
2				
3				
4				
5				
M				

* Days when the tank is frozen up are treated as accumulations

(13) Print in map form (see Fig 12 Wales-Smith (1975b))
$100\ T/\overline{P}_2$, $100\ P_2/\overline{P}_2$ and $100\ \overline{T}'/\overline{P}_2$
using labels T, $\overline{T}'$ and P_2

Tank colour

The systen assumes that the tank is black. If the tank is white the values of T should be about 93% of the value of P_2 and of $\overline{T'}$ obtained from black tanks.

Tank type

The system assumes that tanks are British Standard type. If the tank is a GGI 3000 the value of T should be about 120% of the value of P_2 and of $\overline{T'}$ obtained from British Standard Tanks.

Action

1. One or more n-day totals (of T) appear(s) high or low.

Check daily T values in the period(s),estimate new n-day value(s) and individual day values and discuss with the station authority. If the authority states that an error was made, use their amended figures if they seem reasonable. If agreement can be reached print amended values in brackets. If agreement can not be reached print original total with an asterisk. (Asterisk = discrepancy between T and estimates thereof ($\overline{T'}$ and/or P_2) noted but not resolved).

2. More than one n-day total (of T) appear high or more than one n-day total appear low.

Consult 10.1.4. and Appendix of Wales-Smith (1975b) and check on site, tank management and observational technique. If a serious shortcoming is revealed and can not be removed, publication of the record should cease until it attains acceptable quality. If the necessary changes are made, print agreed, revised values in brackets. If all points are checked thoroughly without revealing any apparent shortcoming the data should be marked with a double asterisk. (Double asterisk = discrepancy between T and estimates thereof ($\overline{T'}$ and/or P_2) investigated but not yet resolved.)

REFERENCES

1. Meteorological Office (1968) Averages of earth temperatures at depths of 30cm and 122cm for the United Kingdom 1931-60. HMSO. London.

2. Penman, H.L. (1948) Natural evaporation from open water, bare soil and grass. Proc.Roy.Soc., Ser A., 193, 120-45.

3. Smith, L.P. (1967) Potential transpiration. MAFF Technical Bulletin 16, 77. HMSO, London, 1967.

4. Wales-Smith, B.G. (1972) Comparisons of estimates and measurements of monthly potential evaporation/transpiration. Evaporation Memorandum No.18. Unpublished material. Meteorological Office Library.

5. Wales-Smith, B.G. (1975a) The estimation of irrigation needs. Engineering Hydrology Today. I.C.E. London 1975, 45-54.

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Fig. 1. a.

ANALYSIS OF MONTHLY TOTALS OF DAILY* VALUES OF EVAPOTRANSPIRATION FROM 27 IRRIGATED LYSIMETERS IN GREAT BRITAIN DURING 1971. (* SOME N-DAY TOTALS INCLUDED)

= NO TOTAL AVAILABLE

= LYSIMETER TOTAL SAME AS PENMAN ESTIMATE

LYSIMETER TOTAL > PENMAN ESTIMATE

LYSIMETER TOTAL < PENMAN ESTIMATE

NUMBER OF LYSIMETERS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
↓	9	11	17	16	21	19	15	16	7	5	3	10
↑	13	13	10	11	6	8	12	9	19	17	20	11
=	1	2						1				3

Fig. 1 b

% BELOW ABOVE

% OF LYSIMETERS

LYSIMETER P.E. BELOW PENMAN P.E.

LYSIMETER P.E. ABOVE PENMAN P.E.

J	F	M	A	M	J	J	A	S	O	N	D
60%	55%	63%	59%	78%	70%	55%	64%	73%	77%	87%	52%

percentages are of lysimeters with totals above or below Penman.

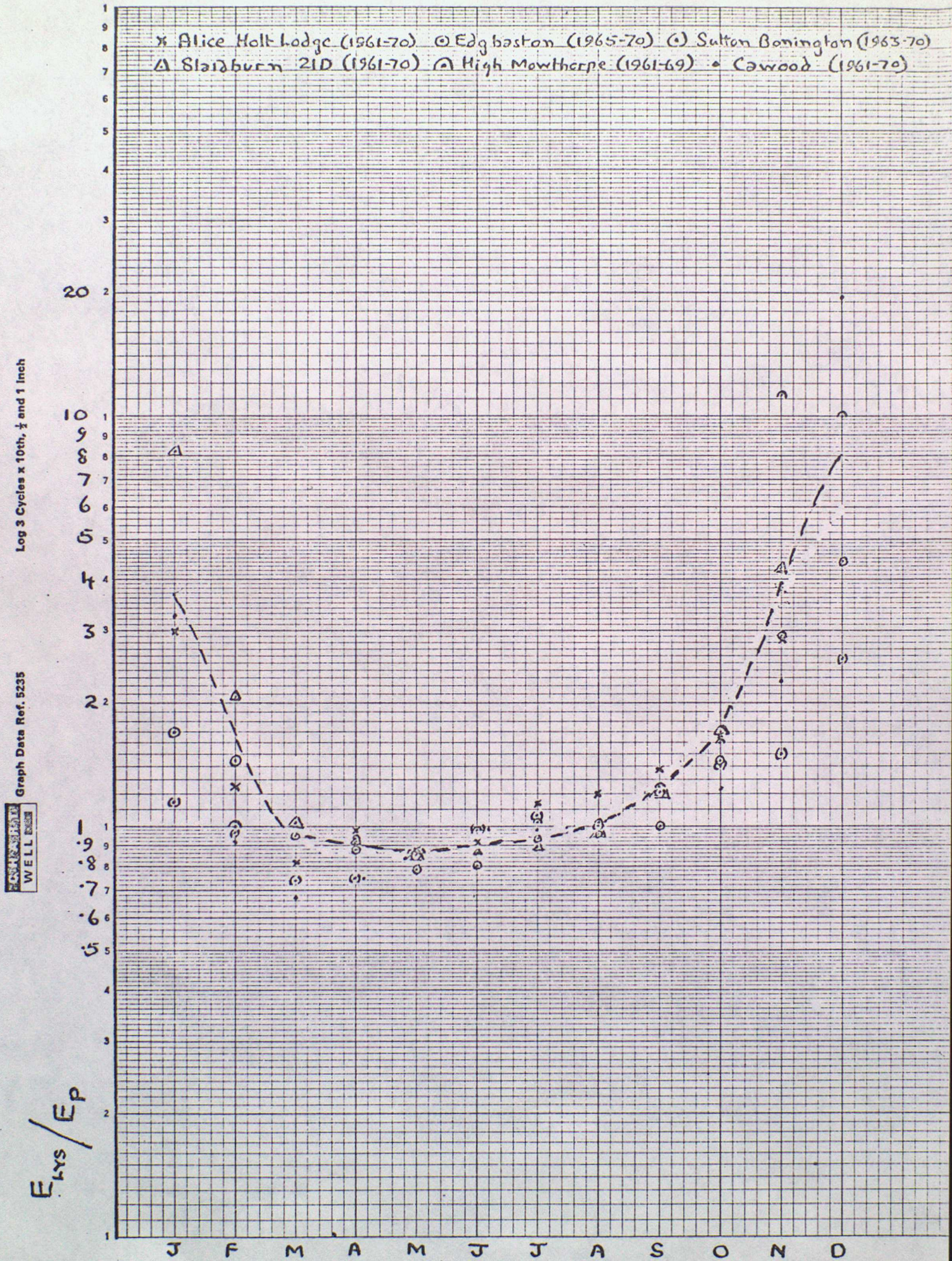
× Alice Holt Lodge (1961-70) ⊙ Edgbaston (1965-70) ⊙ Sutton Bonington (1963-70)
△ Slaidburn 21D (1961-70) ◎ High Mowthorpe (1961-69) • Cawood (1961-70)
Log 3 Cycles x 10th, ½ and 1 Inch
Graph Data Ref. 5235
WELL
E_{LYS}/E_P
J F M A M J J A S O N D
3·80 1·70 ·95 ·92 ·88 ·90 ·95 1·00 1·25 1·70 3·80 7·50

Fig. 2 Empirical factors relating lysimeter and Penman p.e.

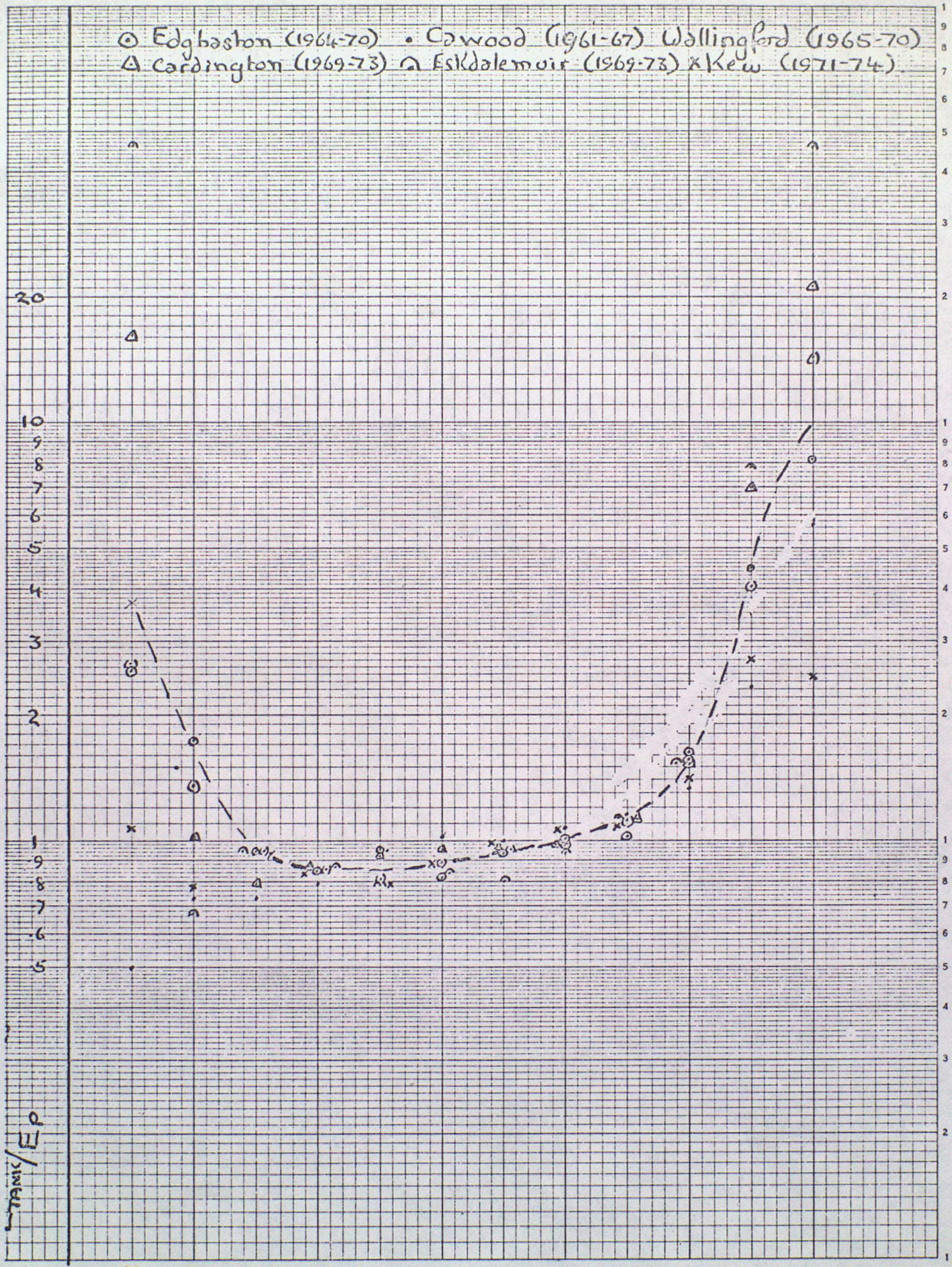

Fig. 3 Empirical factors relating tank (black B. Std) and Penman p.e.

(Data from "Averages of earth temperature at depths of 30 cm and 122 cm for the United Kingdom 1931-60" 1968 HMSO)

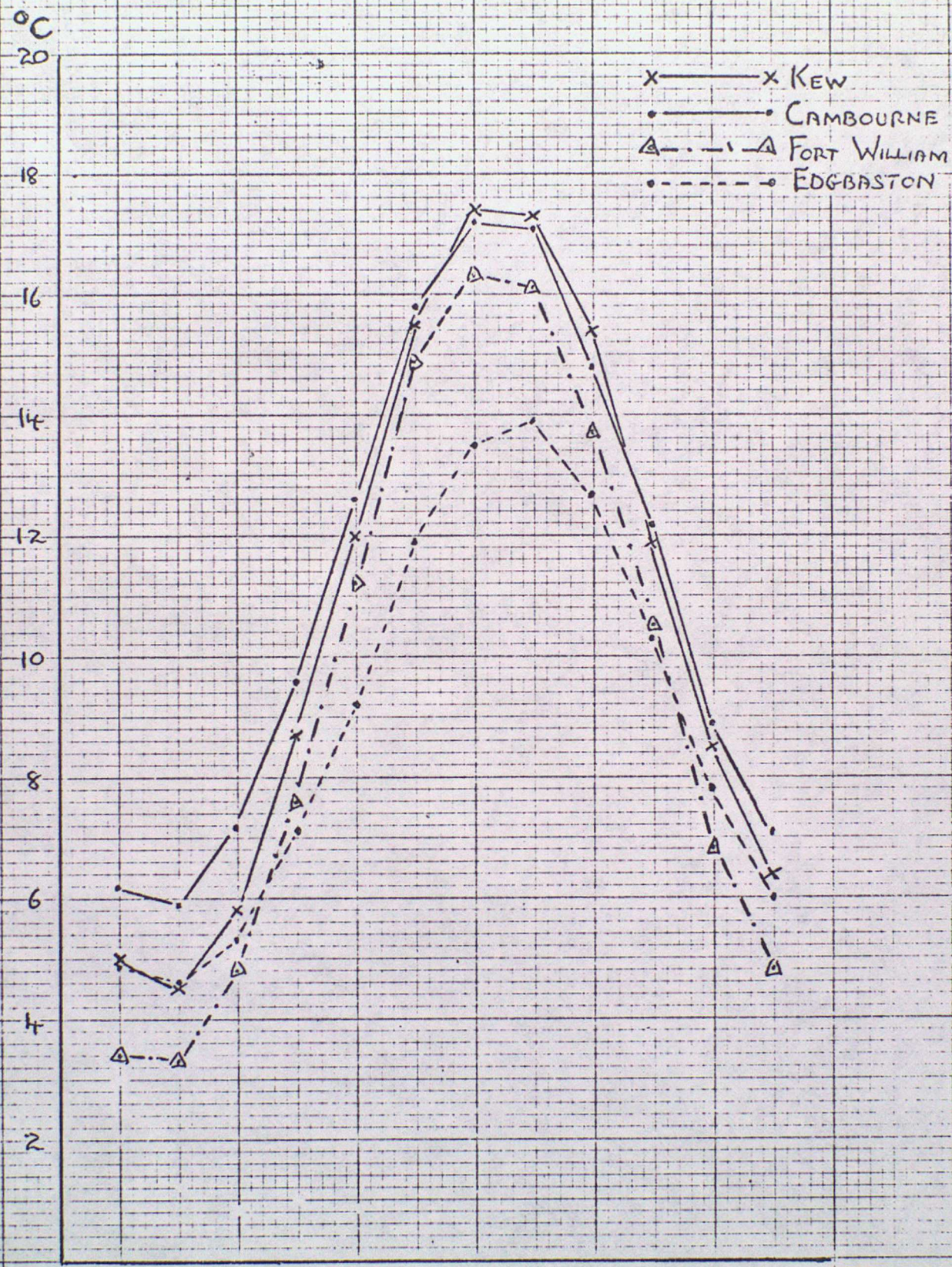

Fig.4 Averages of Earth Temperature at 30 cm 1931-60

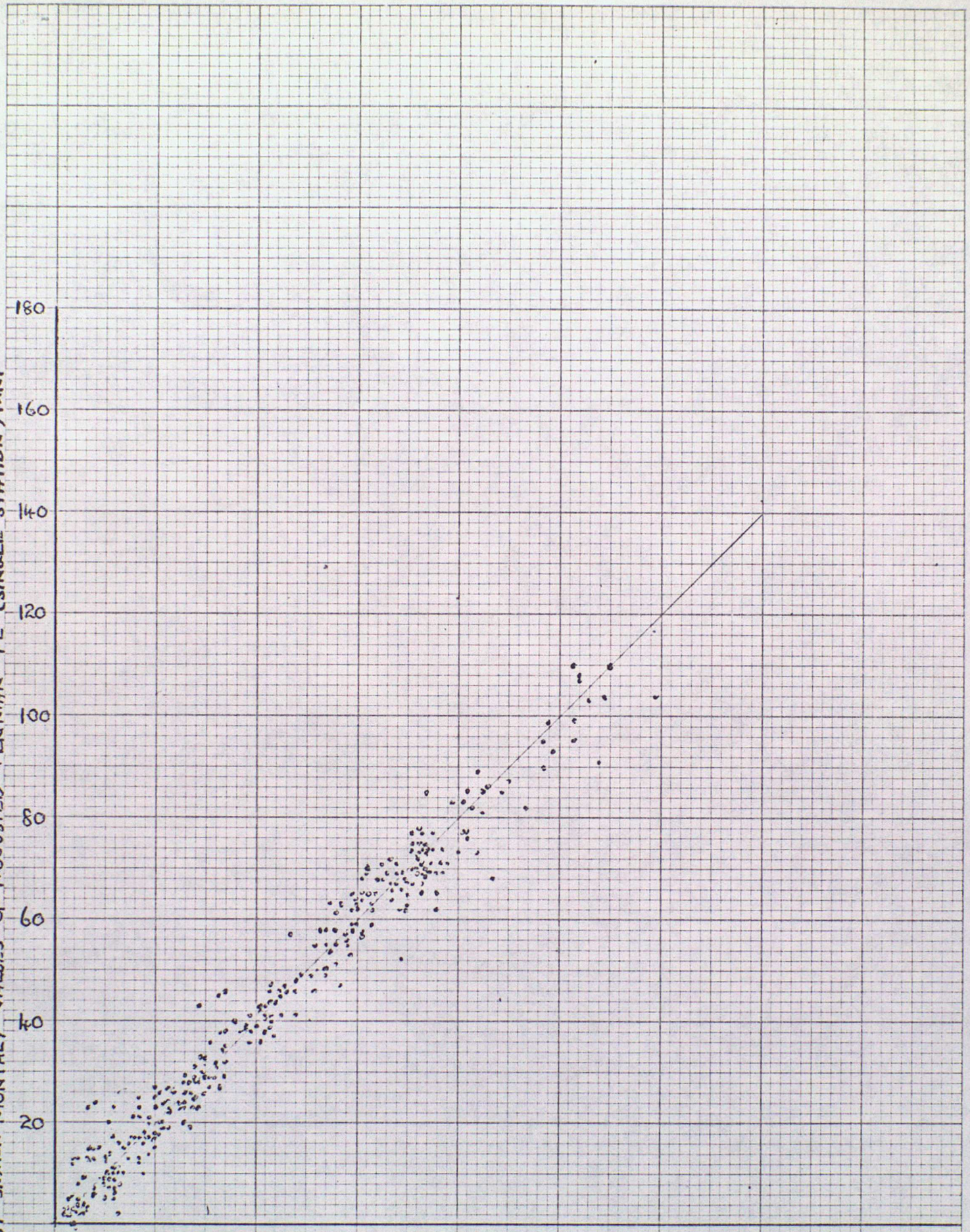

Fig. 5 Comparison of calculated p.e. and estimates thereof from 3 nearest-neighbour stations (27 stations : 1971)